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SOLID ROCKET BOOSTER WATER IMPACT TEST

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16. ABSTRACT

Water impact drop tests have been performed at the MSFC Tennessee River Drop Test Facility. Peak water impact pressures and pressure/time traces were measured for various impact velocities using a two-dimensional, full-scale SRB aft skirt internal ring model. Passive burst disc-type pressure transducers were calibrated for use on flight SRB's. The effects on impact pressure of small ring configuration changes and application of thermal protection system cork layers were found to be negligible.

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INTRODUCTION

The effects of water impact loads on the Space Shuttle Solid Rocket Boosters (SRBs) were recognized early in the shuttle program as one of the most important factors affecting reusability of SRBs. The first two shuttle flights have demonstrated the overall accuracy of analytical and test results pertaining to SRB recovery. Parachute design, cavity collapse loading, water impact acceleration loads, and accompanying stress analyses have been verified by flight data. The STS-1 and STS-2 SRBs did, however, experience greater water impact damage to aft skirt internal components than expected. Damage to skirt stiffening rings ranged from minor to large sections broken away.

Two test programs have been initiated to accurately determine pressures on the aft skirt rings, as part of a project to alleviate the skirt damage problem. One program involves water drops of an 8.56 percent scale model SRB at the Naval Surface Weapons Center. The second test program is the subject of this report, and it involves full-scale drops of a test article at Marshall Space Flight Center (MSFC). The test objectives for the MSFC test were as follows:

1) Dynamically calibrate passive burst disc-type transducers and determine suitability for use on SRB aft skirt rings.

2) Calibrate burst discs mounted on a full-scale two-dimensional SRB aft ring model, and measure pressures on this ring model for water impact velocities up to actual SRB flight impact velocity.

3) Determine the effect on ring pressure and pressure distribution of skirt tab removal.

4) Determine the effect of Thermal Protection System (TPS) cork layers on ring pressures.

TEST APPARATUS AND PROCEDURE

The test set-up is shown in Figure 1. The drops were made in the Tennessee River at the MSFC barge dock. The test vehicle was raised to the desired drop height by a crane. Drop height was determined by lifting the test vehicle vertically over the dock and measuring with the data cable. The crane then rotated, maintaining the same height, until the vehicle was over the desired impact point. Cameras and data recorders were started at a signal from the test engineer who then released the vehicle using a trigger located on the dock. Impact pressure data were recorded on tape in the data trailer. After impact the vehicle was reattached to the crane hook by test personnel in the pick-up boat and hoisted back onto the dock. References 1 and 2 give the test and checkout procedure in detail including release mechanism operation. Checkout drops were made to verify aerodynamic stability of the test vehicle before it was instrumented. Drops with active pressure transducers were then made to establish the drop height/pressure relationship before attachment of burst disc arrays.

The test vehicle details are shown in Figure 2. The body is a 0.25-in.-thick aluminum cylinder, 14-in. in diameter. The first series of tests were performed without the aft skirt ring model and with pressure transducers and burst disc arrays located as shown. The requirements for this test series were documented in Reference 3.

Figure 3 shows the aft skirt ring model in the configuration tested. The modeled portion is a one foot-long two-dimensional section of the aft ring lower profile. End plates two dimensionalize flow of water around the model if the plates are perpendicular to the water surface at impact. The inboard ring flange (transducer 2 is on the inboard flange) supports the skirt thermal curtain by means of a clamping strip called a whalebone. The whalebone adds to the inner flange width and was changed between the first two shuttle flights. The two models shown in Figure 3 include the whalebone in the inner flange dimension. The ring model was tested at 0, 10, and 28 degrees (angle θ in Fig. 2) relative to the drop vehicle.

Various pressure transducer types were used during this test series. Strain gage-type transducers with oil-filled diaphragms transmitting the pressure load to the strain gage were used in the flat plate test. These gages had 0.5-in.-diameter heads and pressure ratings up to 5000 psi. The aft ring model used strain gage transducers with direct load paths. These were 0.19-in. in diameter, rated for 1000 psi, and had frequency response of 3000 Hz. Flight transducers from STS-1 and STS-2 rated at 200 and 400 psi were also used in part of the ring model test. The burst discs were designed to be used in static loading applications such as relief valves and have been proposed as simple devices for determination of aft skirt ring pressures at water impact. A schematic of one disc is shown in Figure 4. The manufacturing tolerance allows diaphragm rupture at 4 percent under to 7 percent above the nominal value. Disc arrays with five discs each were tested as indicated in Figure 2. Nominal burst pressures were 150, 175, 200, 225, and 250 psi for one array; and 150, 200, 250, 300, and 350 psi for the other.

DISCUSSION

Burst Disc Calibration on Flat Plate

Disc and transducer locations for this test were as shown in Figure 2. Drops made to establish the impact pressure versus drop height relationship demonstrated that the oil-filled diaphragm transducers were not suitable for this application. The diaphragms were destroyed by the high accelerations at impact. Limited data were obtained at low drop heights and are shown in Figure 5. The values shown are the peak values of pressure measured. Recessing the transducers and filling the recess with RTV (silicone rubber) were two of the measures taken to protect the transducers. Unfortunately, recessing and RTV were found to affect the pressure reading.

A drop was made from 5 ft (19 ft/sec impact velocity) with burst disc arrays installed. Resulting disc damage is shown in Figure 6. The transducers were recessed 1/2-in. with no RTV and read 140 psi peak pressure for the center transducer and 146 psi for the other. The left array in Figure 6 appears to indicate pressure between 225 and 250 psi and the right array gives inconsistent results with mid range discs broken and low and high pressure discs unbroken. The recessed transducers probably read lower than the actual peak pressures, such that 225 to 250 psi, as indicated by the left array, may be correct. The anomalous behavior of the right array is likely caused by differences in response time of the discs. The larger diameter 150 and 200 psi discs would be expected to have lower frequency response than smaller diameter discs and may, therefore, have been insensitive to the 1-msec order pressure spikes observed.

The pressure/time profiles for the flat plate test article show much sharper pressure spikes than expected for the actual SRB aft ring at water impact. Therefore, a two-dimensional aft ring model was constructed for further testing of the burst discs under conditions closer to the actual SRB water impact.

Burst Disc Calibration on Aft Ring Model

The aft ring model configuration used for burst disc calibration is the one labeled A-A in Figure 3. Burst disc arrays are shown mounted on the aft ring model in Figure 7. The arrays are shown after a 50.7-ft/sec water impact. Note that unbroken 200 and 250 psi discs are blown outward. This condition is apparently caused by water entering the array through vents in the base and through broken discs to produce a back pressure. The results for three drops with burst discs are summarized in Table 1. The discs reacted to the peak water impact pressure within the manufacturing tolerances specified (bursting at nominal -4 percent to nominal +7 percent) except for one of the 150 psi discs in drop one. The 150 psi discs are larger in diameter and would, therefore, be expected to have a longer response time than the other discs. The same two arrays were used in all three drops and as shown in Figure 7, all unbroken discs except 350 psi were wrinkled by the first drop. There were no low pressure disc failures despite this wrinkling.

Pressures measured by the four active transducers as a function of drop height and impact velocity are shown in Figure 8. Transducers 1 and 2 on the outer and inner ring flanges, respectively, were flight instruments salvaged from STS-1. They failed early in the drop series, perhaps because of damage incurred at STS-1 water impact. The 132-ft drop height corresponds to 92-ft/sec impact velocity, which was the STS-1 condition. The peak pressure measured for this condition was 820 psi, as shown. Typical pressure/time traces for the ring model water impact event are shown in Figure 9.

The Effect of Skirt Tab Removal on Ring Model Pressure

Stress analysis results have shown that water impact induced stress in the skirt aft ring can be reduced at the intersection of ring web and outer flange by removal of the skirt tab. The tab is 1.75 in. of skirt which extends below the ring outer flange (view B-B of Fig. 3). The stress analysis used the assumption that water impact pressure is unchanged by removing the tab. A brief drop test series was conducted to verify this assumption before implementation of tab removal on the STS-3 flight SRBs. The test configuration was as shown in B-B of Figure 3. Drops were made from 50, 70, and 90 ft with and without the tab. There was no Thermal Protection System (TPS) cork on the model for this test.

Unfortunately, an important variable, water entry angle, was not controllable during these drops due to interaction of wind and drop vehicle. The data are shown in Figure 10 (without tab) and Figure 11 (with tab). The data curve from configuration A-A web pressures in Figure 8 is reproduced on these figures for comparison. The data in Figure 8 were taken on a calm day and represent near zero entry angle. Consideration of the data with and without skirt tab indicates similar data scatter and no observable affects of tab removal. It is also seen that configuration differences between A-A and B-B had no significant effect on water impact pressures. Data taken with θ = 10 and 28 degrees using the device shown in Figure 2 were discarded since total vehicle angle was unknown.

Effect of Cork on Ring Model Pressure

The aft ring in the SRB aft skirt is thermally protected by 0.5 in. of cork over much of its surface. A series of water drops was made to determine the effect of this cork layer on water impact pressure. The configurations tested are shown in Figure 3, view B-B. Drops were made with 0.5 in. of cork covering the web and outer flange and, then, with 1.0 in. of cork on the web and 0.5 in. on the outer flange. The transducers were mounted flush with the ring web and flanges, as in previous tests. A thin layer of RTV was used for the transducer/cork interface to insure even and complete pressure load transmittal.

The effect of cork thickness on ring web pressure is shown in Figure 12. It is seen that cork has no effect on peak water impact pressure. Typical pressure/time traces for the 92-ft/sec impacts are shown in Figure 13. The trace for the 1.0 in. of cork configuration shows an unusual step, but basically the traces show the same amplitudes and time durations. Figure 14 shows flange pressures for the cork test. The outer flange transducer with 0.5 in. of cork gave unreasonably high pressures at 40- and 80-ft drop heights. There may have been an irregularity in the RTV at the cork/transducer interface which caused this. Pressures on the inner flange were very consistent and repeatable and of the same magnitude as web pressures. Figure 8 shows lower flange pressures, but they were measured with the salvaged and possibly damaged flight transducers, as discussed earlier. The flange pressures indicated for the inner flange in Figure 4 are believed to be more reliable.

RESULTS

Passive burst disc-type pressure transducers were found to be suitable for water impact peak pressure measurements on SRB aft skirt rings. The discs burst at peak pressures within the manufacturer's specification (nominal disc burst pressure -4 percent to nominal +7 percent) when the pressure pulse duration was typical of SRB water impact, 0.004 sec. Erratic disc burst behavior was observed for shorter duration pulses.

Peak pressures measured on an SRB skirt aft ring model ranged from 700 to 850 lb/in.^{2} for the maximum expected SRB water impact velocity, 92 ft/sec. The pressure pulse duration was approximately 0.004 sec at this impact condition. Pressures were near the same on the ring web and flanges.

Small changes in ring configuration, skirt tab removal and inner flange widening, did not produce a measurable pressure change.

Layers of TPS cork 0.5- and 1.0-in. thick bonded to the ring did not significantly change the peak water impact pressure or the pressure/time trace.

REFERENCES

1. SRB Components Pressure Disk Water Impact Calibration Test and Checkout Procedure. SRB-DT-TCP-001, August 21, 1981.

2. SRB Components Water Impact Drop Test and Checkout Procedure. SRB-DT-TCP-002, December 8, 1981.

3. Pressure Disk Water Impact Calibration Preliminary Test Requirements. ED01-81-82, June 29, 1981.

TABLE 1. BURST DISC/ACTIVE TRANSDUCER CORRELATION

WATER IMPACT		PEAK PRESSURE, LB/IN²	DISC CONDITION[1]
DROP HEIGHT, FT	VELOCITY, FT/SEC		
40	50.7	192	(150) 150 (175) (200) 200 225 250 250 300 350
60	62.1	318	(150) (150) (175) (200) (200) (225) (250) (250) 300 350
65	64.7	375	(150) (150) (175) (200) (200) (225) (250) (250) (300) 350

[1]PARENTHESES INDICATE BROKEN DISCS

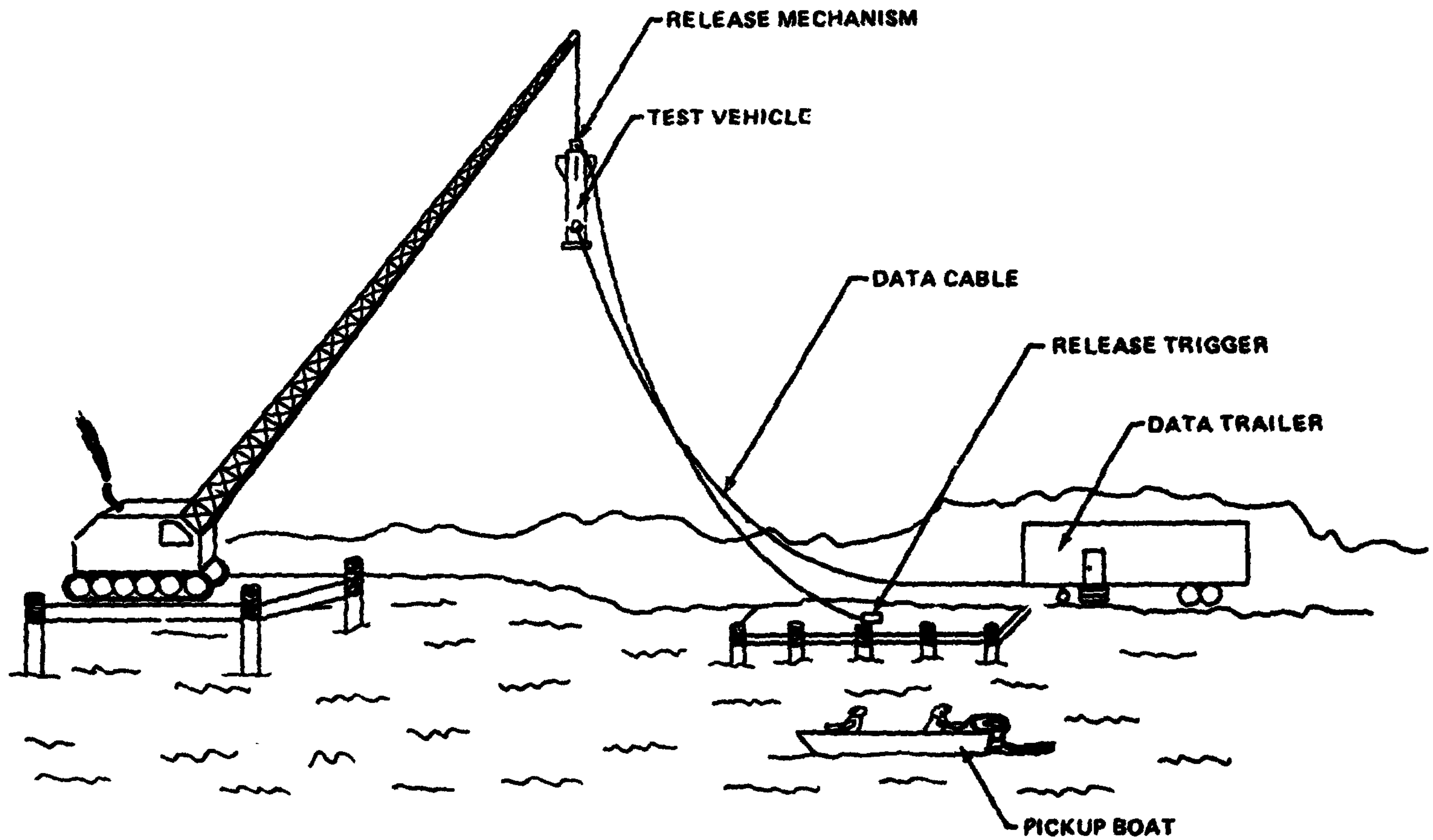

Figure 1. Test setup.

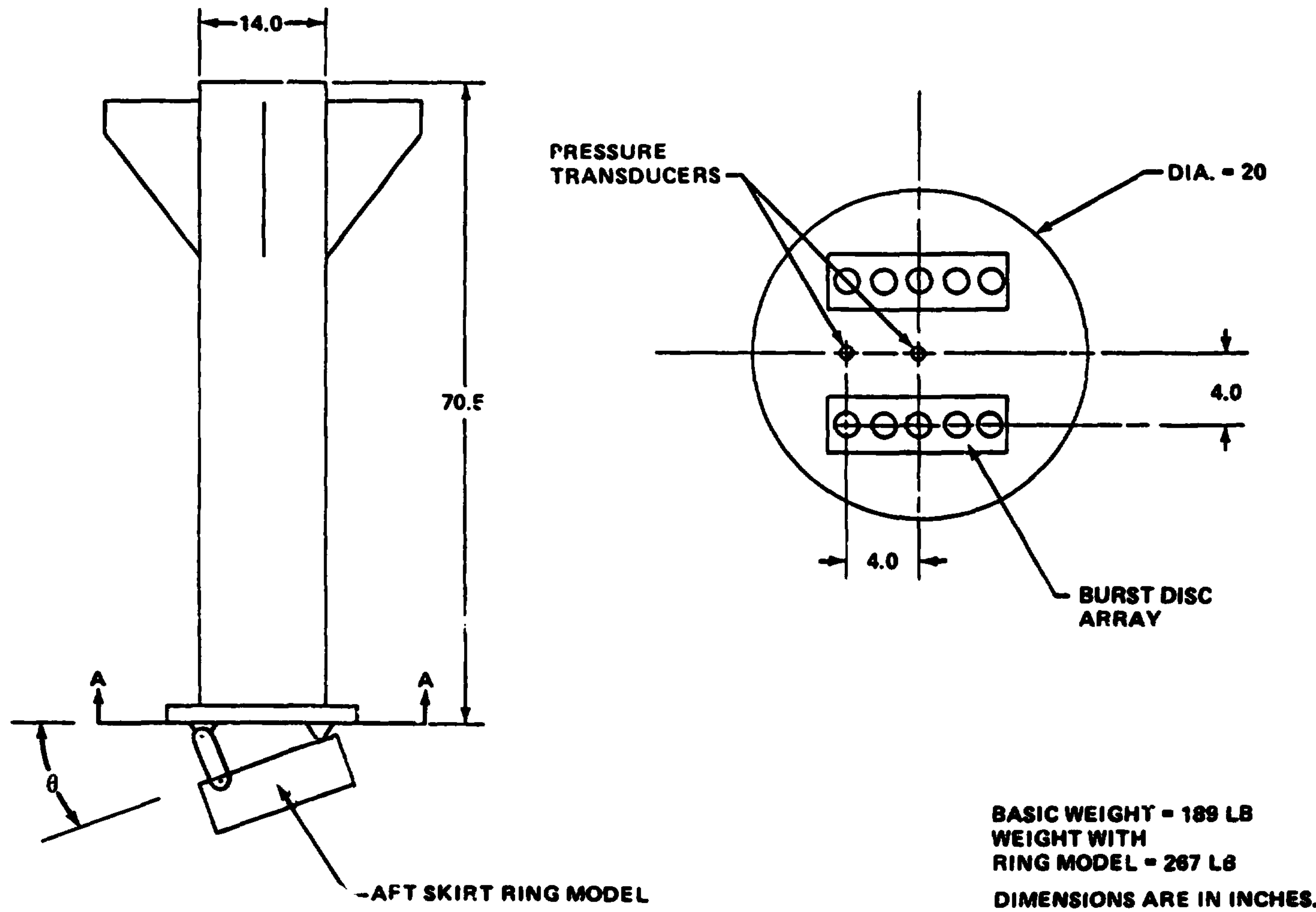

Figure 2. Test vehicle.

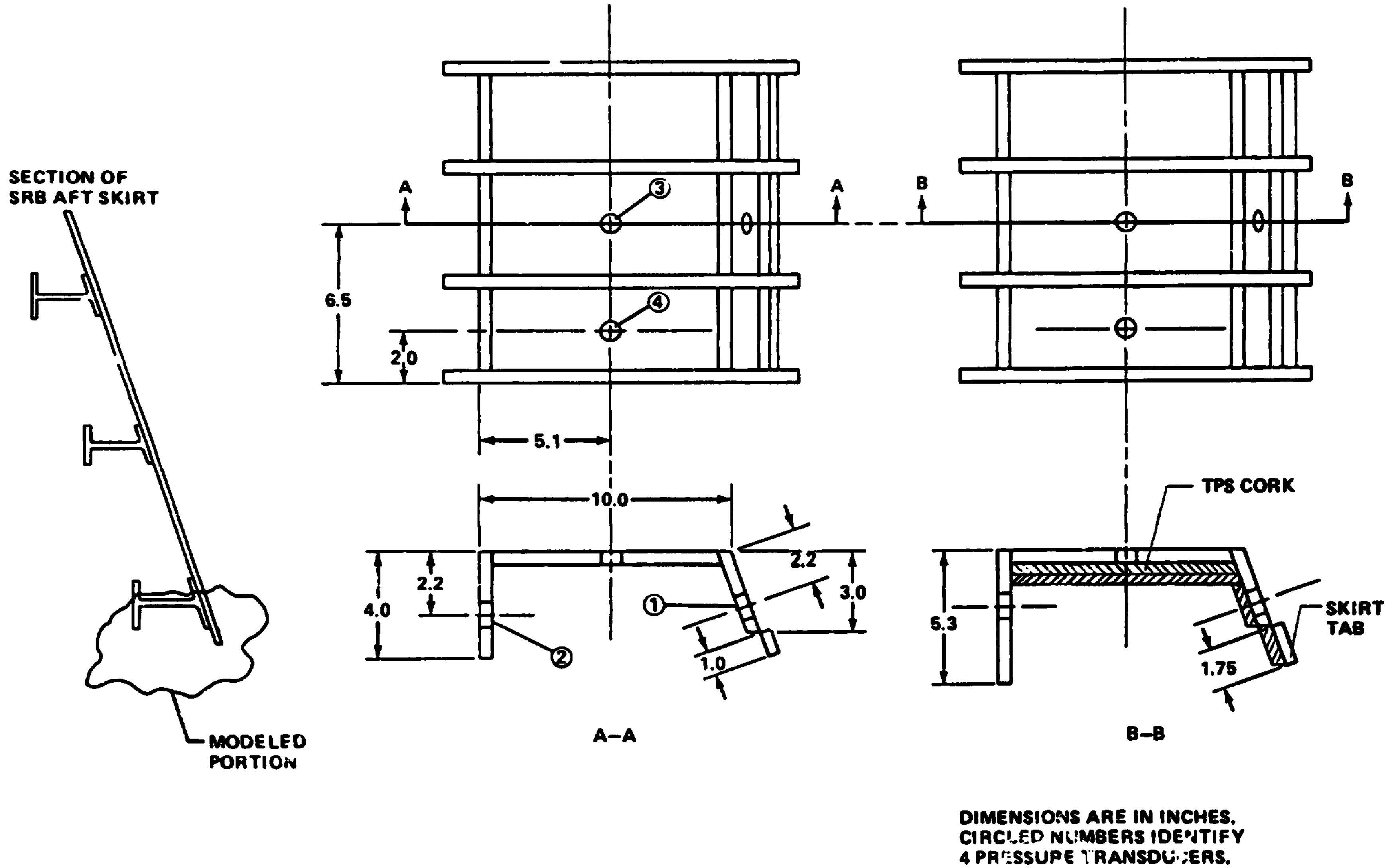

Figure 3. Aft skirt ring model.

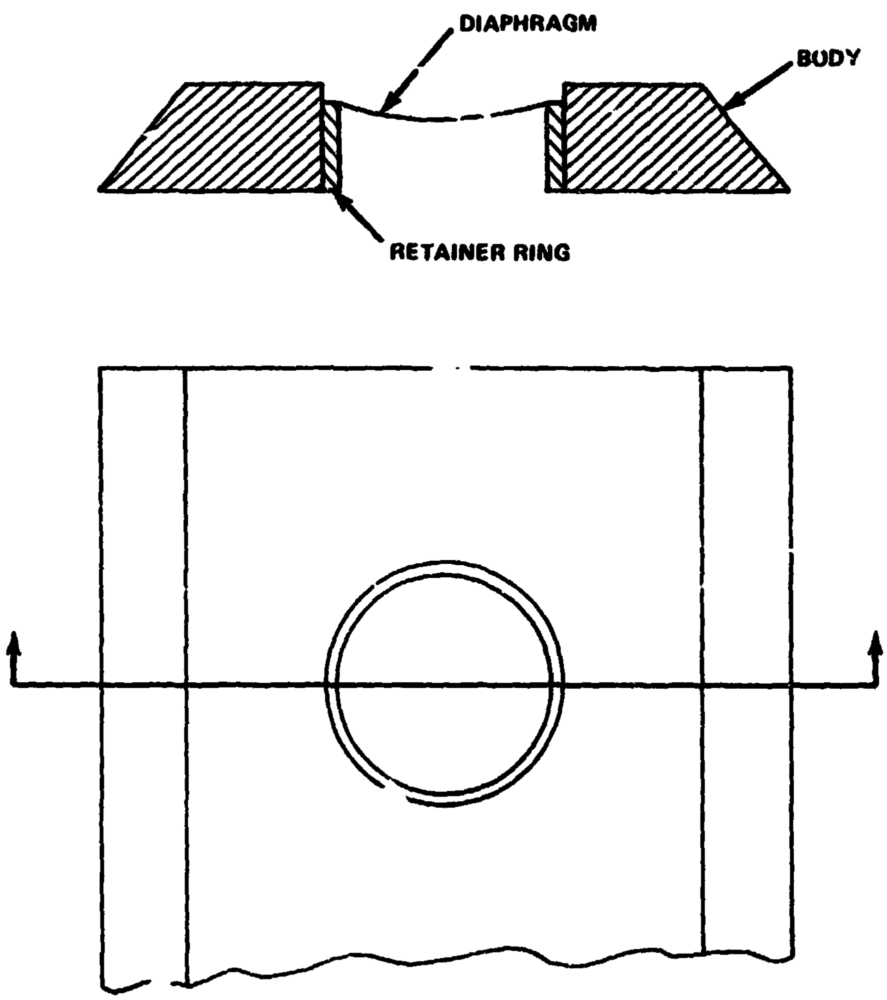

Figure 4. Burst disc schematic.

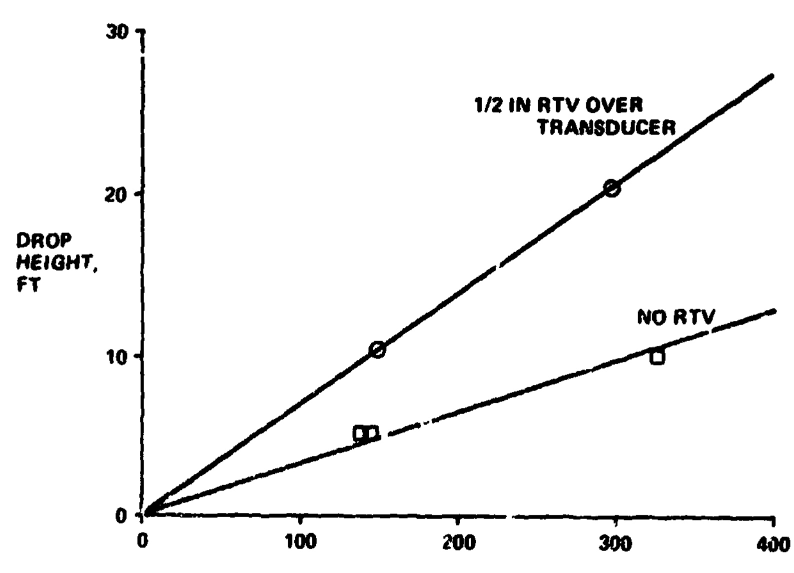

Figure 5. Flat plate test pressures.

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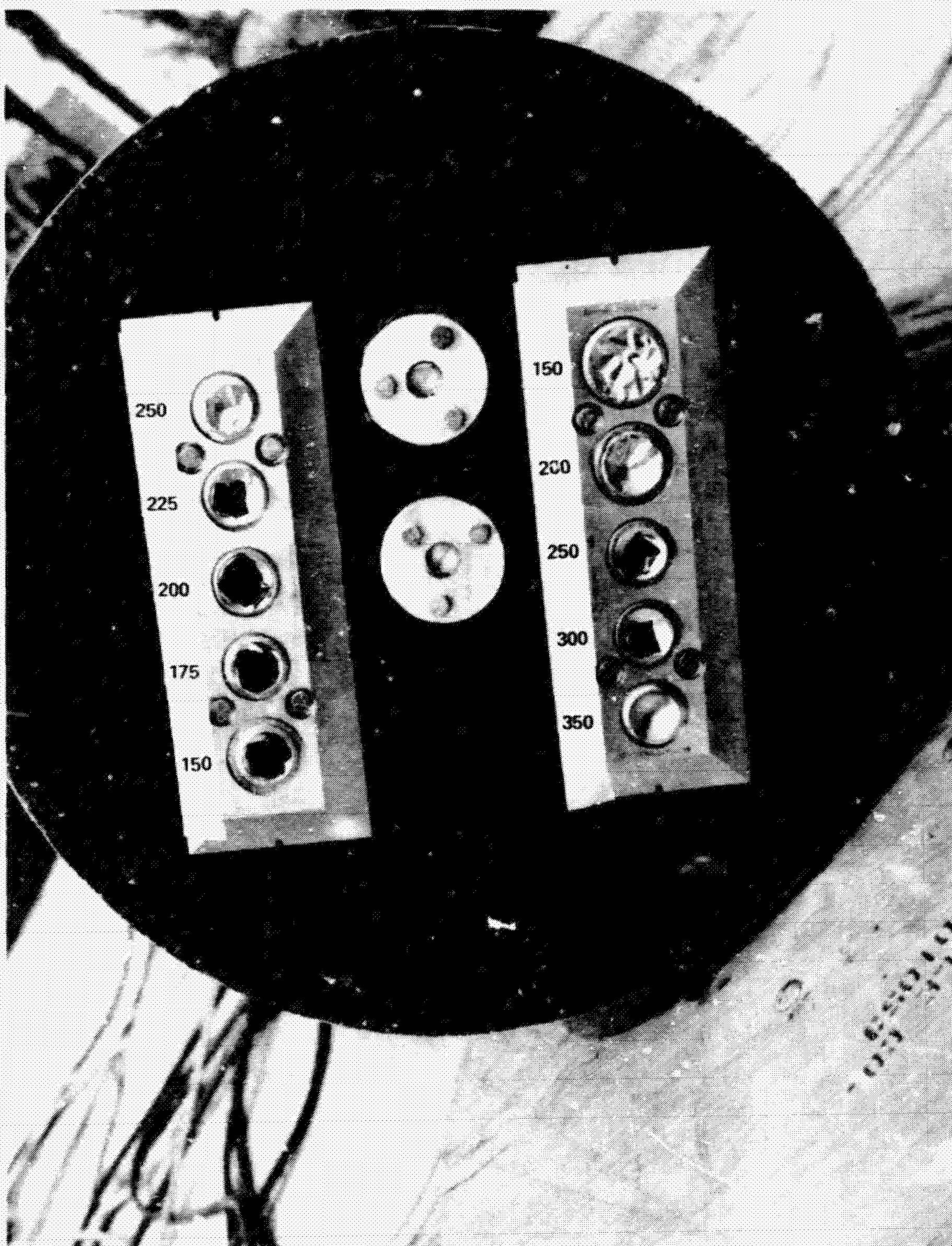

Figure 6. Burst discs after 5-ft drop, flat plate model.

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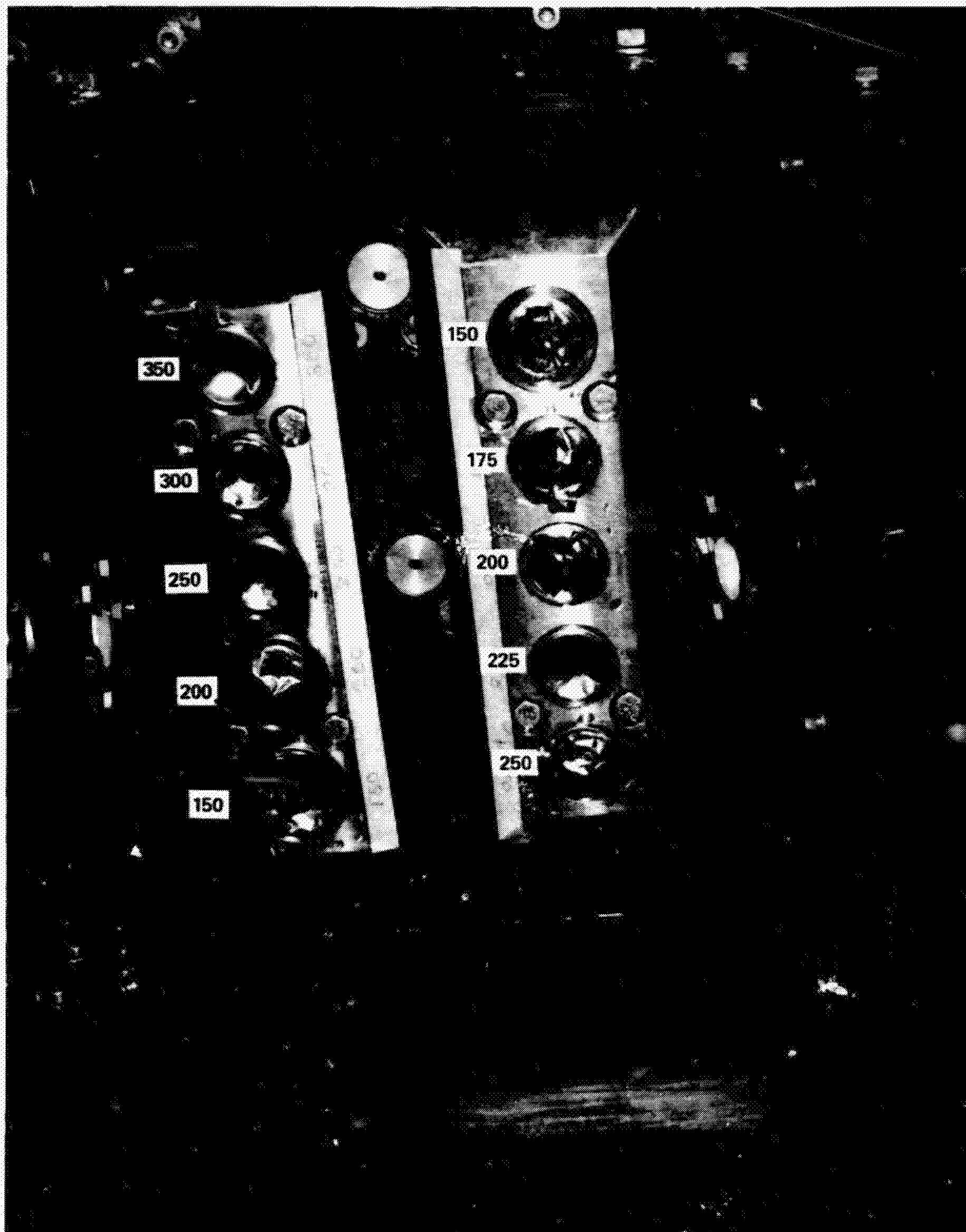

Figure 7. Burst discs on ring model (40-ft drop).

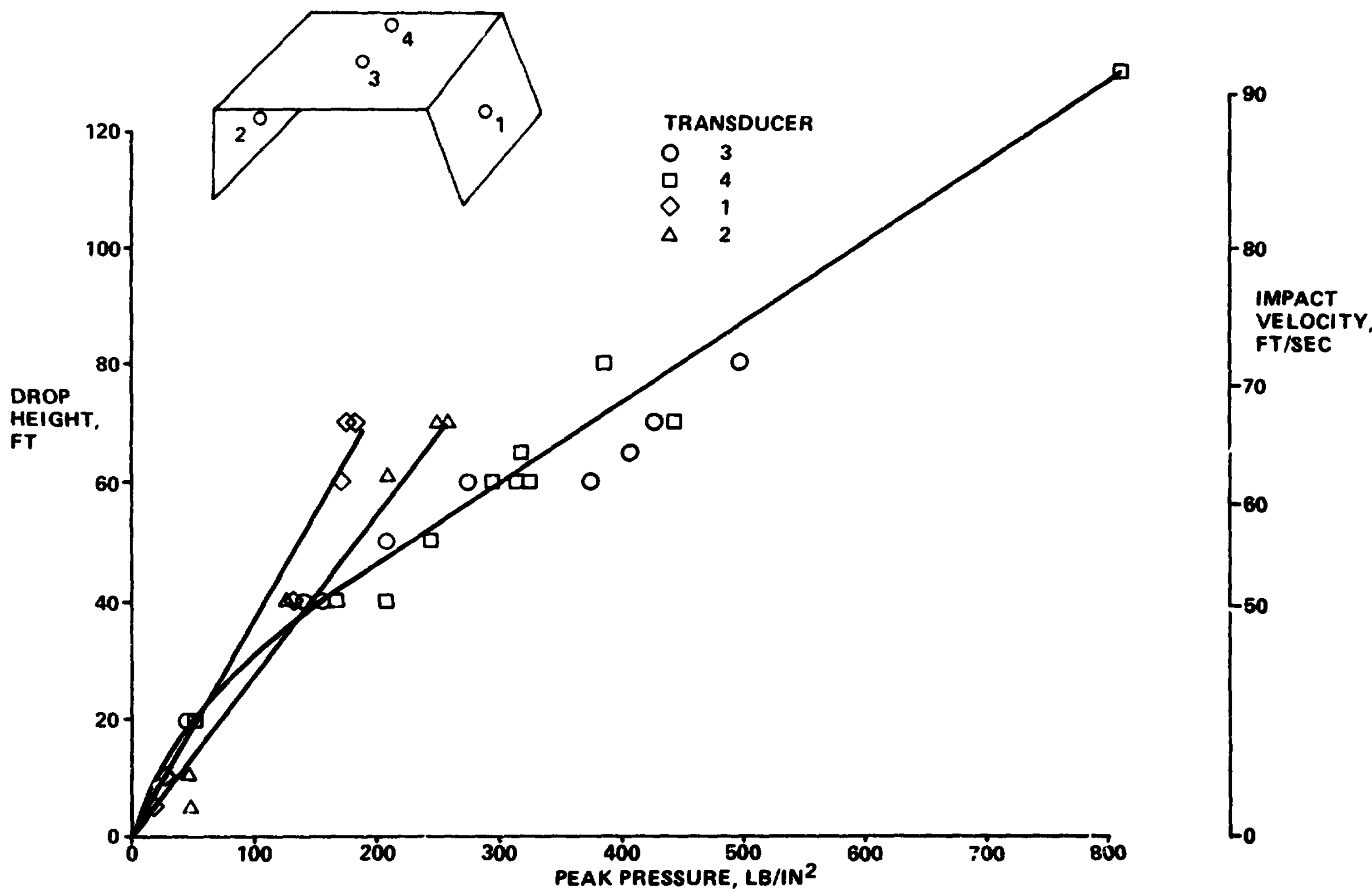

Figure 8. Aft ring model pressures.

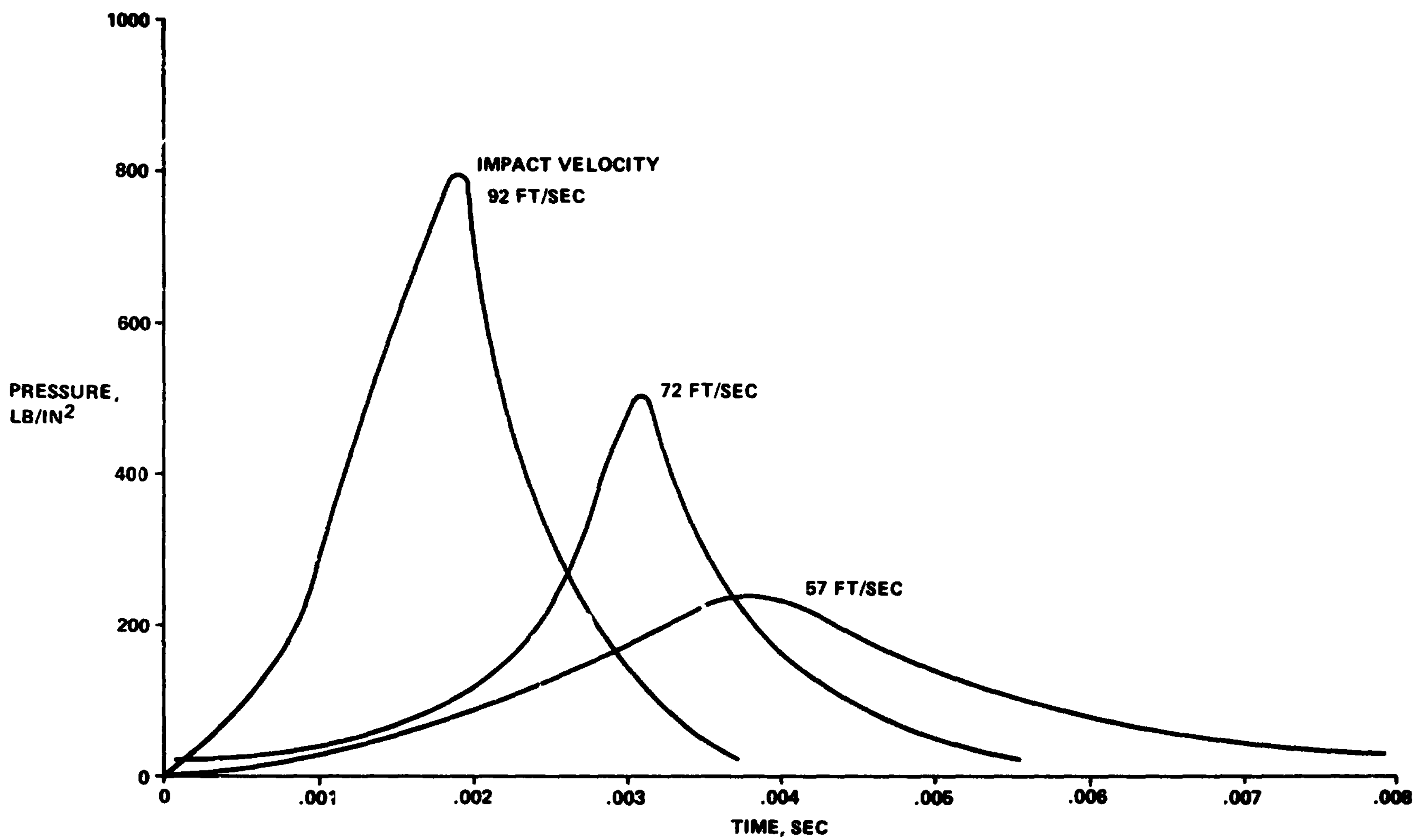

Figure 9. Typical ring model pressure/time traces.

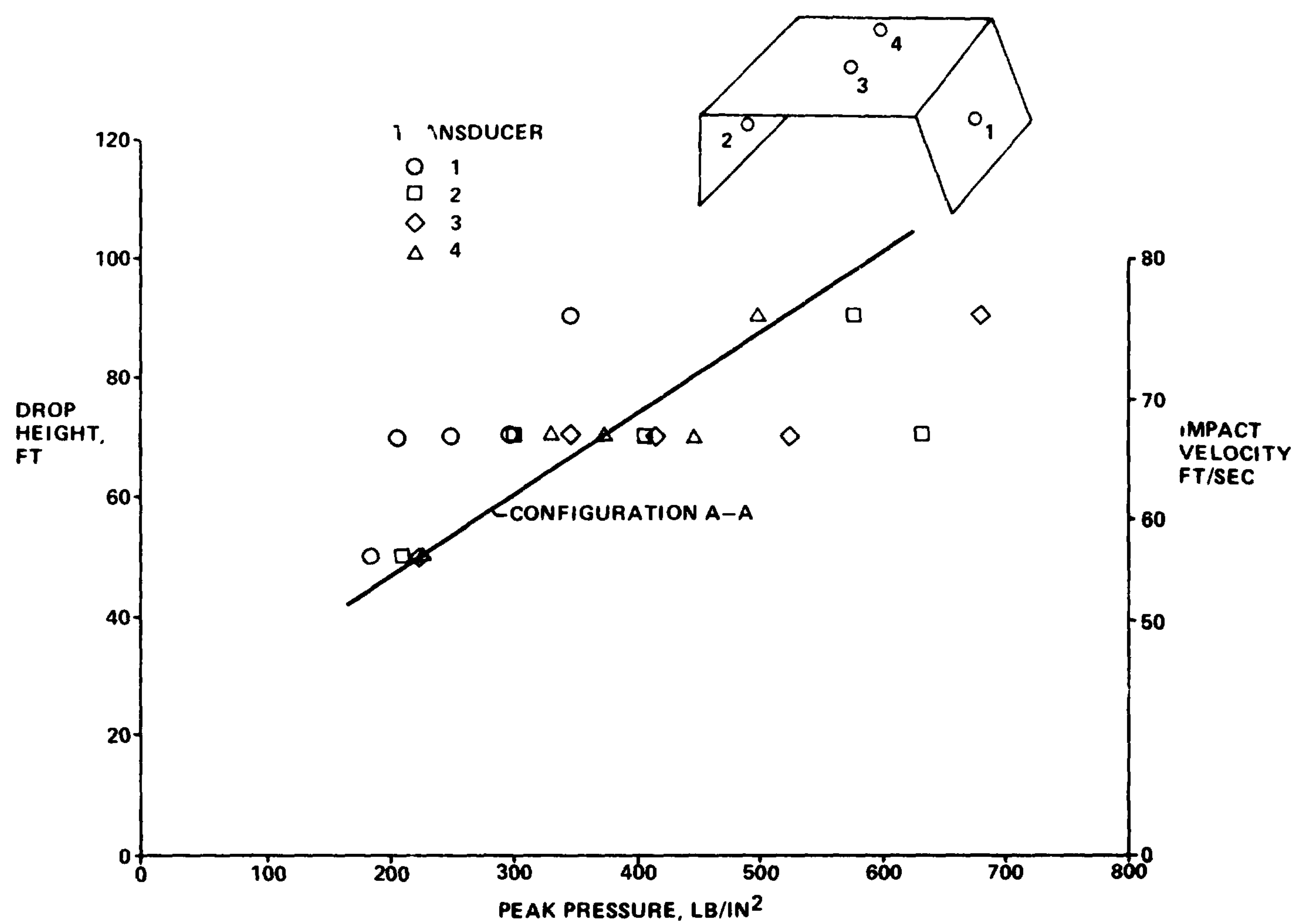

Figure 10. Aft ring model pressure without skirt tab.

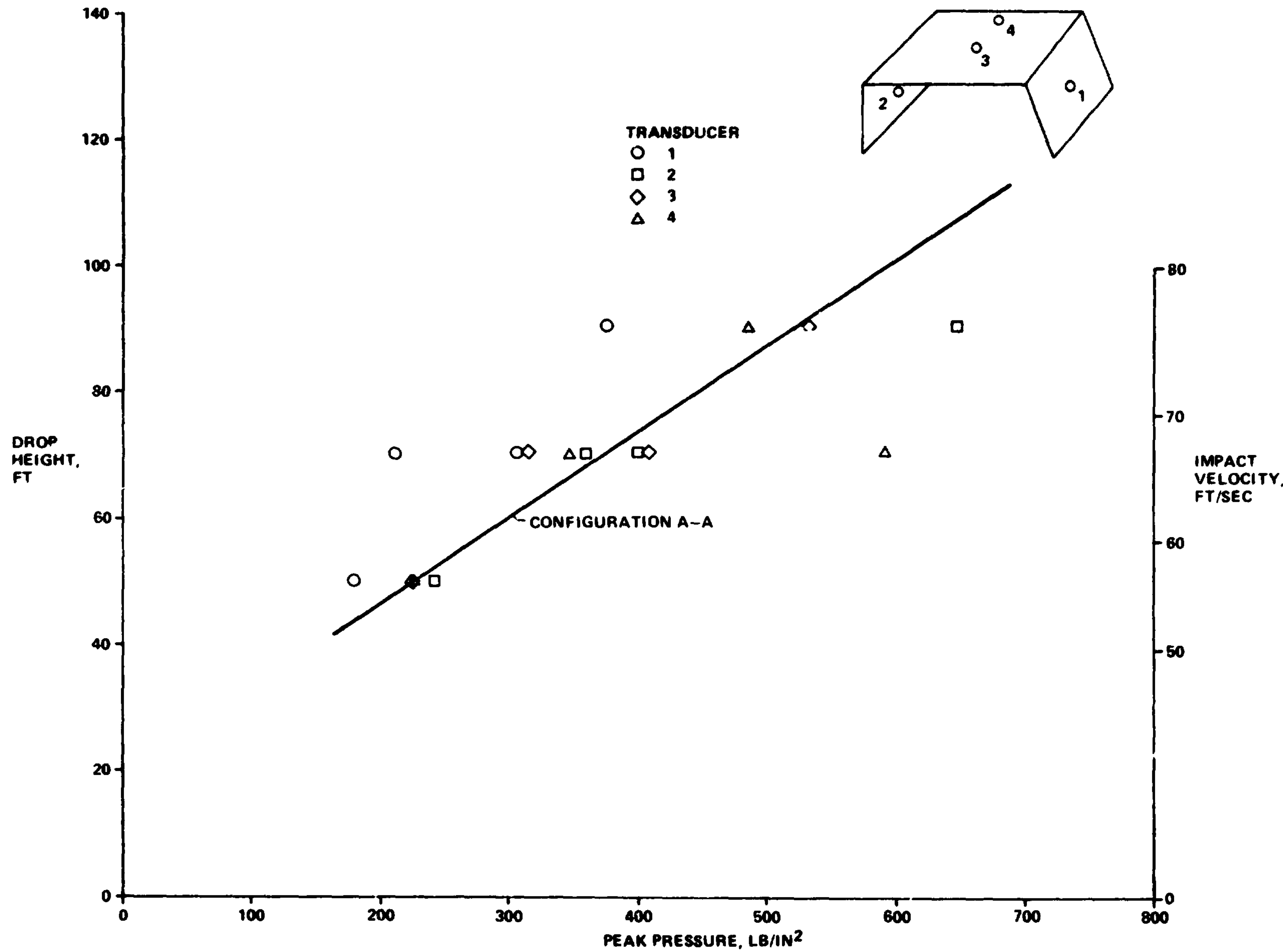

Figure 11. Aft ring model pressure with skirt tab.

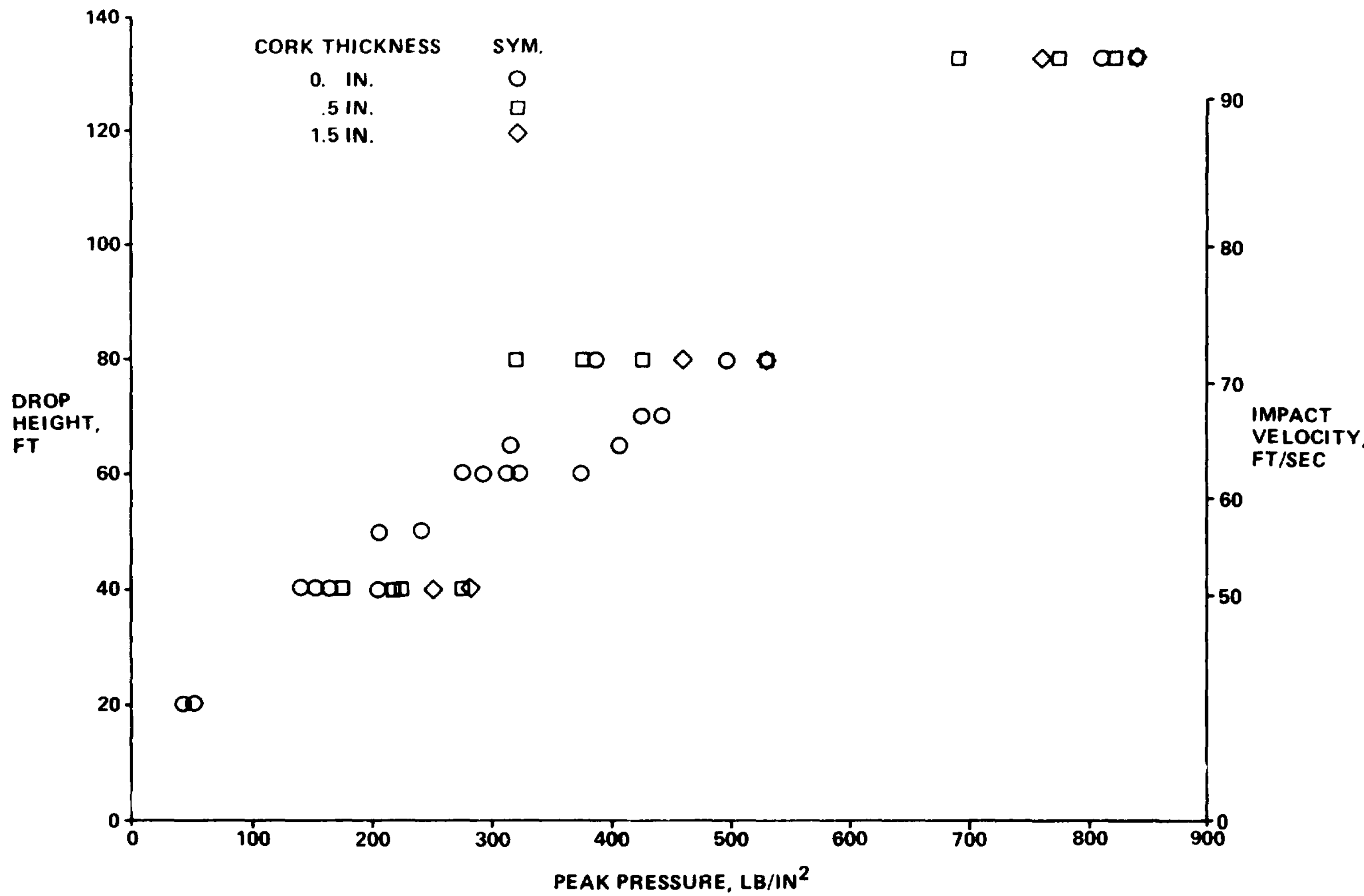

Figure 12. Effect of cork on ring web pressures.

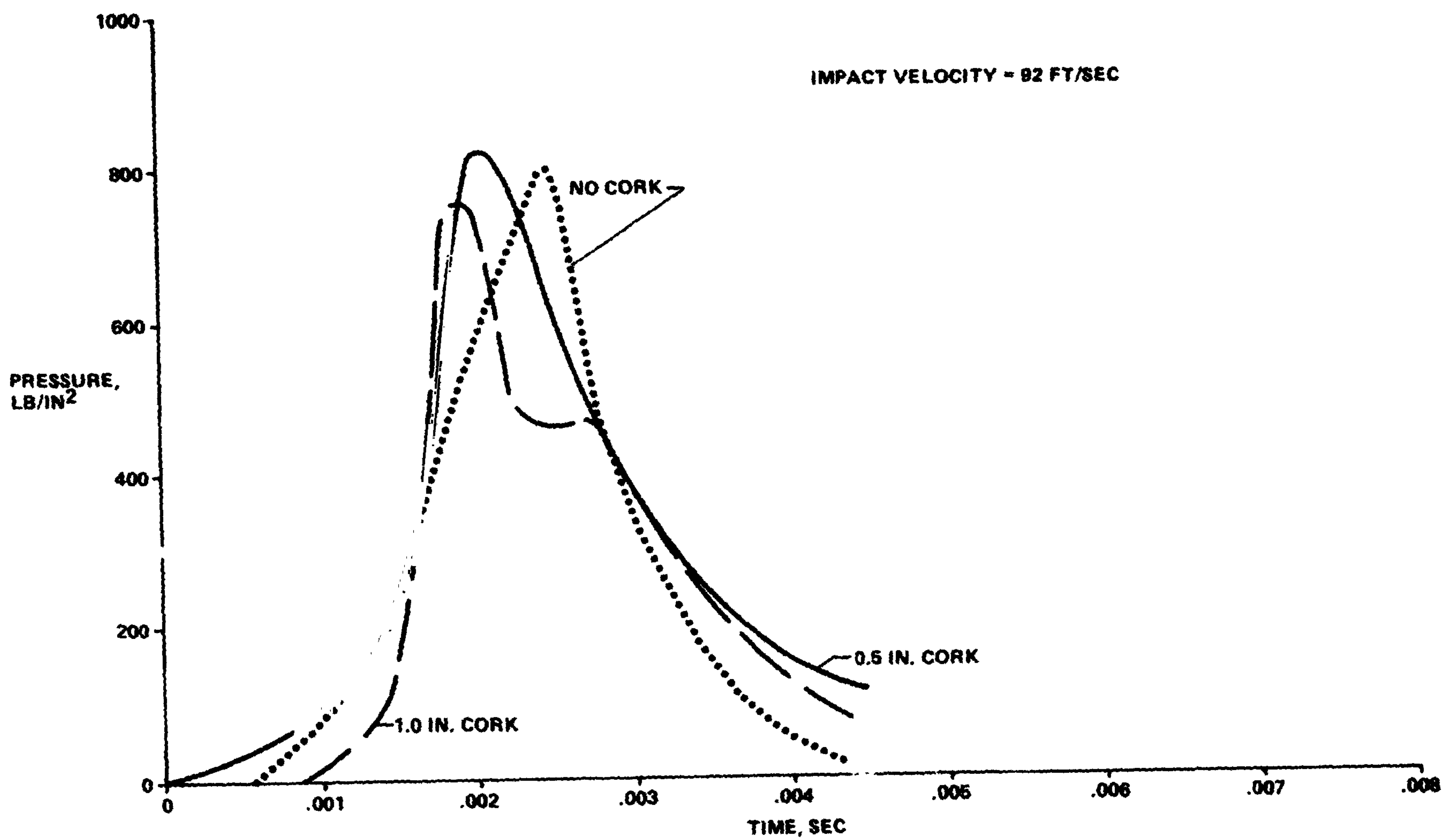

Figure 13. Effect of cork in pressure/time trace.

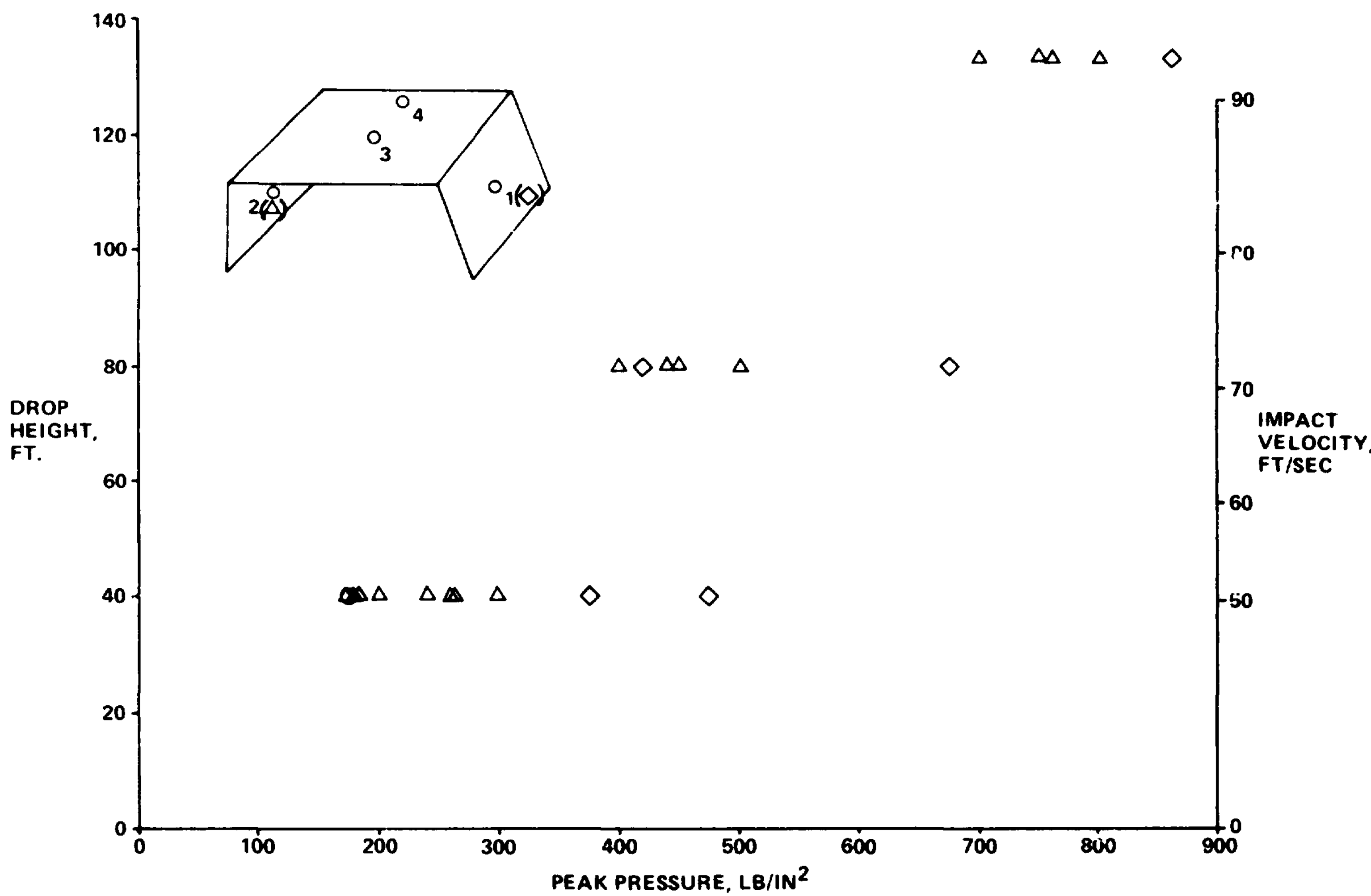

Figure 14. Flange pressures for cork test.

APPROVAL

SOLID ROCKET BOOSTER WATER IMPACT TEST

By Frank Bugg

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

G. F. McDonough
Director
Systems Dynamics Laboratory

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